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The Effects of Postoperative Activity on

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in Orthopedic Surgical Patients

by

John A. Kenney

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Abstract

The Effects of Postoperative Activity on Subcutaneous
Tissue Oxygen Tension and Blood Flow
in Orthopedic Surgical Patients

by John A. Kenney

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Wounds are particularly vulnerable to perfusion and oxygenation deficits. Subcutaneous tissue oxygen tension ($P_{sc}O_2$) and subcutaneous blood flow (BF_{sc}) reflect the balance between oxygen delivery and oxygen consumption in the periphery and are influenced by a variety of factors. Exercise has been associated with an increased rate of wound healing and in normal subjects, increased blood flow to peripheral tissues. The effect of activity on peripheral oxygen and blood flow in injured individuals is not well documented. This study compared the early postoperative effects of an enhanced postoperative activity plan with conventional postoperative activity on $P_{sc}O_2$ and BF_{sc} in orthopedic surgical patients. Using a randomized two group experimental design, ten orthopedic surgical patients scheduled for total hip replacement were assigned to conventional postoperative activity or enhanced activity. $P_{sc}O_2$ was measured (using a silastic tonometer, fiberoptic/fluorescent oxygen sensor placed next to the surgical wound) on postoperative days 0, 1, and 2 while patients breathed room air and 50% O_2. Baseline (on room air) $P_{sc}O_2$ was significantly different (F=21.94; p=0.0016) between activity protocol groups; measurements ranged from 40±15 to 50±7 mmHg (mean ± SD) in the experimental group and 58±7 to 72±14 (mean ± SD) in the control

group. The study hypothesis that enhanced activity increases $P_{sc}O_2$ was not supported.

BF_{sc} or perfusion was calculated using the Fick principle. Patients were classified according to their $P_{sc}O_2$ response to breathing 50% oxygen. No group differences were identified (Mann Whitney U test). Percent $P_{sc}O_2$ increase ranged from 27 ± 6 to 43 ± 38 (mean $\pm$ SD) in the experimental group and 15 ± 10 to 73 ± 15 (mean $\pm$ SD) in the control group and was found to be significant (F=2745.7; p=0.0087) for time, without regard for protocol These findings did not support the study hypothesis that enhanced activity increases $P_{sc}O_2$.

Due to the small sample, gender bias between groups, and preliminary nature of the data, no conclusions were made regarding the affect of enhanced postoperative activity on $P_{sc}O_2$ and BF_{sc}. Recommendations for the design and focus of future studies are discussed.

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Chapter I

Statement of the Problem

Wound healing or self-repair of damaged tissue is an essential survival function of all living organisms. With few exceptions, every patient who undergoes surgery, sustains a traumatic injury, or endures a chronic illness such as diabetes or peripheral vascular disease, encounters tissue damage and must deal with a healing wound. Approximately 20% of all emergency room patients, and 33% of all home health care patients require management of wounded tissue (Baxter, 1993). In many situations the wound is a source of potential morbidity and mortality and may be the central focus of hospitalization and/or rehabilitation. In a recent survey, sited by Baxter (1993), over 63% of the patients cared for by nurses assigned to four home health care agencies had wounds which failed to heal after 40 days of treatment. A major goal of health care activities is to promote healing of wounds. As hospital costs rise dramatically a mandate for shorter hospital stays, quicker return to normal activity, and avoidance of wound complications necessitates better treatments to produce quicker, stronger wound healing. Wounds which fail to heal or develop complications place a significant financial and emotional burden on patients and health care facilities.

Nurses have traditionally assumed an active role in wound healing management by providing postoperative conditions which maximize healing potential. Research studies have identified several deleterious variables which affect proper wound healing and

may be modified using medical and/or nursing therapeutics. Foremost among these variables are malnutrition, tissue hypoxia, anemia, infection, diabetes, psychologic stress, compromised immune status, and physical trauma to the wound (Orgill & Demling, 1988; Hunt, 1988; Zurier,1979).

Since wound repair is characterized by rapid synthesis of new cells and collagen, maintaining adequate blood and oxygen supply to healing tissue is critical to timely, uncomplicated tissue repair (Jonsson, et al., 1991; Niinikoski, 1977). Oxygen is the critical component of many of the physiological responses which comprise the wound healing process (Sheffield, 1988; Hunt, 1976; Jonsson, et al., 1991). A multitude of studies have reported that in many types of wounds, improving tissue oxygenation results in parallel gains in tissue repair (Mangalore, Pai, & Hunt, 1972; Niinikoski, 1977; Knighton, Halliday & Hunt, 1984; Kuhne, Ullmann & Kuhne, 1985; Butler, Ham, Lafferty, Cotton, & Roberts, 1987; Jonsson, Hunt & Mathes, 1988; Rabkin & Hunt, 1988; Jonsson, et al., 1991; Hopf et al., 1992). At a time when sufficient tissue perfusion is most essential, many patients, especially the aged, experience inadequate tissue perfusion due to increased peripheral vascular resistance, decreased alveolar-capillary exchange, decreased microvasculature, underhydration and less efficient neurovascular regulation (Jones & Millman, 1990; LaVan & Hunt, 1990).

Many medical practitioners recognize the importance of oxygen in the physiologic mechanisms of healing. Their clinical prescriptions often include activities to enhance arterial circulation

by ensuring adequate hematocrit, cardiac output, and blood pressure. Researchers have discovered that these efforts often fail to provide adequate tissue perfusion (Chang, Goodson, Gottrup & Hunt, 1983; Jonsson, Jensen, Goodson, West & Hunt,1987). Only direct measurement of tissue oxygen tension can provide an accurate assessment of tissue perfusion.

Accepted nursing interventions designed to improve systemic oxygenation include incentive spirometry, secretion clearance, positioning, and supplemental oxygenation (Whitney, 1989). These activities may also fail to provide adequate tissue perfusion. What then can be done to improve tissue perfusion? Do pain control, environmental temperature, or post-operative activity affect tissue oxygenation?

Post-operative activity has long been prescribed as a therapeutic intervention for surgical patients. In both animal and human studies, exercise has been associated with the rate of wound healing (Newberg, 1943; Wong, Lotke, & Ecker, 1986; VanRoyen, O'Driscoll, Dhert & Salter, 1986) and increased blood flow to peripheral tissues (Nielsen, Staaberg, Nielsen & Sejrsen, 1988). Studies to determine how enhanced activity and exercise can provide the best conditions for rapid tissue repair are needed.

Given the importance of promoting tissue oxygenation to healing wounds, the limitations of current post-operative interventions in ensuring adequate perfusion, and the potential applications of enhanced activity and exercise it is critical to investigate what additional forms of therapy can be taken to ensure improved tissue

perfusion. It is the intent of this investigator to explore the effects of early postoperative activity on subcutaneous oxygen tension of surgical patients.

Chapter II

Conceptual Framework

The past decade of scientific investigation has resulted in a tremendous growth in the knowledge of the physiology of wound healing and its application to clinical practice. The focus of this conceptual framework is to describe basic concepts and review recent research in wound healing physiology, the role of oxygen in wound healing, mechanisms of tissue oxygenation, and the body's physiological response to post-operative activity.

Wound Healing Physiology

Tissue injury, whether from accident, surgical incision, or disease activates a highly integrated series of biological events directed at healing the damaged tissue. The sequence of events associated with wound healing is commonly divided into three physiological phases: inflammation, proliferation and maturation (Cooper, 1990).

Inflammation

Inflammation includes activities of hemostasis and the activation of various chemically mediated systems which direct the migration of specialized cells to the wound area.

Hemostasis.

At the moment of injury, blood vessels are damaged and three physiologic responses act to stem the flow of blood: vasoconstriction, platelet aggregation, and blood coagulation. Vasoconstriction is a contractile response of vascular smooth muscle caused by mechanical stimulation to the vessel and perivascular nerves. Platelet aggregation is initiated by damage to the vessel endothelium resulting in platelet adherence at the site of injury. As platelets adhere, they release: 1) adenosine diphosphate and thromboxane A_2 which facilitate additional platelet adherence, 2) serotonin which enhances vasconstriction, and 3) thromboplastin which speeds coagulation (Berne & Levy, 1990). Exposure of platelets to the negatively charged collagen in the subendothelium causes a release of Hageman factor which activates a cascade of reactions resulting in the degranulation of platelets and formation of a dense structure of fibrin strands. The fibrin network traps platelets and red blood cells forming a clot which is impermeable to plasma (Wahl & Wahl, 1992). This clot serves to seal off the injury, prevent further bleeding and bacterial infection, and provide a structure for further tissue repair. Blood clots formed in each damaged vessel create intravascular thromboses and cause a reduction of previously adequate circulation. Tissue hypoxia, local acidosis and lactate accumulation result (Rabkin & Hunt, 1988).

Chemically Mediated Activities.

The second activity of the inflammation phase includes activation of various chemically mediated systems which direct vasodilation of capillaries, chemotaxis, and opsonization of microbes. Capillary vasodilation opens junctions between capillary epithelial cells and allows movement of cells and fluids through capillary walls resulting in wound redness, swelling, fever, and pain. This vasodilation is caused by several factors within the wound: 1) kinins (bradykinin and other potent vasodilator peptides) released by platelets early in the inflammation response, 2) complement factors, a cascading system of protein factors produced by the liver and monocytes, activated by the presence of microorganisms or blood coagulation (Groer & Shekleton, 1989), and 3) histamine, serotonin and eicosanoids, other potent vasodilators, released by mast cells in response to degradation of certain complement factors (Robson & Heggers, 1992).

Chemotaxis is a process where cells respond to and move towards areas of increasing concentration of certain chemical factors (Grotendorst, 1992). It is presumed that these chemoattractants regulate the order and number of cells which enter the wound, with each cell type responding to specific attractants. 1) Leukocytes, specifically polymorphonuclear neutrophils are attracted by kinins and complement factors and accumulate in the wound within a few hours of injury. A primary function of these neutrophils is to serve as the first line of defense against bacteria through both oxygen dependent and oxygen independent phagocytosis

mechanisms (Wahl & Wahl, 1992). 2) Monocytes/tissue macrophages are attracted by chemotaxic agents produced by platelets and found in the complement system. Phagocytes arrive soon after the neutrophils and persist in the wound for several days. They participate in wound debridment, microbicidal activities and collagen synthesis. Macrophages in turn release chemotaxic factors to attract more macrophages to the wound site (Pollack, 1981). 3) Connective tissue cells (fibroblasts) are attracted by collagen, fibronectin, and platelet derived growth factor (Grotendorst, 1992).

Opsonization, the attachment of a complement factor to bacteria or foreign proteins so that the reticuloendothelial system can recognize and phagocytize the cell or substance is the final activity of the inflammation phase of wound healing (Groer & Shekleton, 1989). The combination of physiologic activities during this stage, hemostasis, vasodilation, and chemotaxis, are predictable events which serve to control injury, clear the wound of infection and debris, and provide substrates for tissue repair. These activities usually occur within the first three days of injury.

Proliferation

Proliferation, the second phase of wound healing, begins on approximately day 5 post injury and continues for two to four weeks (Pollack, 1981). The key wound activities of this phase include formation of granulation tissue, neoangiogenesis, contraction, and epithelialization.

Formation of Granulation Tissue.

Fibroblasts are the principle operative cells in the formation of wound granulation tissue. In uninjured tissue, fibroblasts are sparsely distributed throughout connective tissue, but within hours of an injury fibroblasts migrate to the wound site in response to chemotaxic agents secreted by macrophages and released by dead platelets (Morgan & Pledger, 1992). Upon arrival at the wound site fibroblasts proliferate and produce collagen, elastin, and proteoglycans. Tropocollagen, a preliminary form of collagen is formed through a complex process involving the hydroxylation of proline and lysine which is dependent on the presence of iron, ascorbic acid and oxygen. Eventually tropocollagen is converted to collagen which together with proteoglycans forms tissue to fill in the wound area. (Pollock, 1987).

Various factors such as platelet derived growth factor (PDGF), transforming growth factor (TGF-ß), and lactate synthesized by macrophages stimulate and regulate fibroblast activity (Morgan & Pledger, 1992). Given the necessary substrates, the wound quickly gains strength as deposited collagen fibers band together, cross link and overlap to form a network in the injured area. Intense synthesis and secretion of collagen by fibroblasts continues for 2-4 weeks (Pollack, 1981). Because they depend on one another, collagen deposition and vessel growth require a delicate balance. The synthesis and deposition of collagen depends on construction of new vessels to supply required metabolic materials (Hunt, 1988).

Neoangiogenesis.

Neoangiogenesis, a process of endothelial cell migration and proliferation resulting in new capillary networks, normally occurs only during embryonic development, ovulation, menstruation, inflammation and tissue repair. Sensing the lower oxygen tension of injured tissue, macrophages and mast cells release potent angiogenesis factors (Orgill & Demling, 1988; Knighton et al., 1983). In response to these angiogenic stimuli, outgrowths or "buds" begin to form on pre-existing venules. The vascular basement membrane on the side of the "buds" is degraded and endothelial cells begin to migrate across the membrane in the direction of the stimulus (Whalen & Zetter,1992). As the endothelial cells migrate they send out cytoplasmic processes to establish contact with other cells. As other cells are contacted from the other side of the wound or from adjacent tissue, the patterns for capillary loops are defined (Hunt, 1988). Other endothelial cells follow the migrating cells and proceed to divide and differentiate to form a lumen and eventually a new capillary basement membrane. These new vessels promote and support the work of fibroblasts in cellular granulation. The angiogenic process generally remains localized to the wound area and stops as healing is completed (Whalen & Zetter, 1992).

Contraction.

Wound contraction is the normal process by which the edges of an open wound seem to be drawn toward the center to close the

wound. Actually the forces of contraction are generated uniformly throughout the wound rather than being localized at the wound margins (Rudolph, 1979). Although the process of contraction is not well understood, it is thought that the granulation tissue which fills the open wound contains modified fibroblasts with characteristics of smooth muscle. These myofibroblasts, are capable of contraction and their actions reduce the size of the wound. Another theory suggests ordinary fibroblast units contribute to rearrangement and compression of the connective tissue matrix. (Rudolph, Berg, & Ehrlich, 1992). In sutured wounds myofibroblasts are not found and contraction appears to be a very limited process (Pollack, 1981 and Hunt, 1988).

Epithelialization.

The final division in the proliferative phase of the wound healing process is epithelialization which involves vertical migration of cells from the residual epithelium. In response to various growth factors, epithelial cells from the basal cell layer at the wound periphery detach from their basement membrane, divide and migrate toward and across the wound (Orgill & Demling, 1988). Trailing epithelial cells (a sheet one or two cells thick) follow the migrating front and proliferate to generate enough cells to cover the wound. Once a single layer develops, additional layers evolve from mitotic division of the epidermal cells. If the basement membrane zone remains intact (as in superficial wounds), wound closure is

rapid. If the basement membrane zone is destroyed, epithelialization is much slower.

Wounded epidermal cells are exposed to fibronectin and vitronectin, proteins found in blood. These proteins influence epidermal proliferation and cell migration (Stenn & Malhotra, 1992). Various molecules, known collectively as cytokines, are released from platelets, macrophages, muscle cells and epithelial cells which orchestrate and support epithelialization (Stenn & Malhotra, 1992). Wound oxygen tension levels (as discussed later in this review) are closely related to the rate of epithelialization (Pai & Hunt, 1972).

Maturation

Maturation, the third phase of wound healing, usually begins about day 21 and may extend from several months to years (Orgill & Demling 1988). During this phase disorganized collagen fibers are removed and replaced with well organized fibers along lines of mechanical stress resulting in a stronger wound. This remodeling is accomplished through 1) breakdown of excess or poorly organized collagen by collagenase and other proteases, 2) deposit of new collagen with increased fiber cross-linking, and 3) reduction of surface capillaries as metabolic demands diminish.

Wound tensile strength is usually about 25% of normal at 3 to 4 weeks and 70% to 80% after several months (Orgill & Demling, 1988). Normally, removal and deposition of collagen proceeds in equilibrium so there is no net gain or loss of collagen during the maturation period. On occasion collagen synthesis exceeds collagen

lysis and hypertrophic scarring and keloid formation is seen (Doughty, 1992). When wound blood flow is reduced (causing hypoxia and malnutrition) or infection is present a net loss of collagen results which leads to a weakened wound, wound breakdown or dehiscence (Orgill & Demling, 1988).

The Role of Oxygen in Wound Healing

An extremely critical factor in the healing of wounded tissue is the maintenance of adequate tissue oxygenation. Abundant molecular oxygen must be present for cellular processes of oxidative phosphorylation, oxidation, and oxygenation (Sheffield, 1988). An impressive array of animal and human research demonstrates that lowered tissue oxygenation leads to impairment of wound healing while optimal tissue oxygenation enhances wound healing. The following studies identify how wound tissue oxygenation impacts collagen synthesis, epithelialization, angiogenesis, and microbicidal function of leukocytes.

Oxygen and Wound Collagen Synthesis

Oxygen is required for energy (ATP) production and hydroxylation of proline and lysine molecules, the building blocks of collagen. Several molecules of ATP must be produced and consumed to insert each amino acid into the collagen chain. The energy for this ATP synthesis could be met by anaerobic metabolism, but severe acidosis would result before significant collagen could be

made (Hunt, 1976). Hypoxic environments inhibit fibroblasts from producing adequate amounts of functional collagen. Juva, Prockop, Cooper, and Lash (1966) found anoxic fibroblasts in vitro produced an intracellular polypeptide collagen precursor, but failed to release it. When oxygen was made available, collagen once again was produced. Silver's research (1980) found that if all other substrates and cofactors are present in sufficient quantities, the rate at which collagen is hydroxylated will increase in response to changes in pO_2 from 0 torr to approximately 50 torr.

In their study of collagen accumulation in experimental rabbit wounds Hunt and Pai (1972) found exposure to moderate hyperoxia accelerated collagen synthesis. Assuming constant tissue perfusion, raising arterial pO_2 from 82 to 200 torr increased collagen accumulation and synthesis 50%, while decreasing arterial pO_2 from 82 to 42 torr depressed collagen synthesis by 50%. These findings are essentially identical to animal studies conducted by Niinikoski (1969).

To determine the correlation of tissue oxygen tension and collagen deposits in humans, Jonsson et al. (1991) monitored experimental wounds in 33 surgical patients. A statistically significant correlation between tissue oxygen tension ($P_{sc}O_2$) and collagen accumulation in the wounds was identified. They found that the most tissue-hypoxic patients accumulated collagen at a rate of 1/3 the rate of tissue-hyperoxic patients. These studies clearly indicate how improved oxygen delivery promotes collagen synthesis.

Oxygen and Wound Epithelialization

Epithelialization is a very limited activity in primarily closed wounds, but in open wounds a combination of contraction and epithelialization closes the wound. Oxygen has been linked to the replication rate of epithelial cells and wound closure. In 1972, Pai and Hunt created full thickness experimental wounds in rats to determine whether epithelialization could be changed by ambient pO_2 at one atmosphere. They found the rate of epithelialization was 15% faster during continuous exposure to 45% oxygen compared to exposure to room air. Pai and Hunt concluded that contraction appeared independent of ambient oxygen tensions. Epithelial cells can derive some portion of their oxygen from the air as observed when wound dressings which exclude access to atmospheric oxygen retard epidermal healing (Silver, 1980), but the main source of epithelial cell oxygen in open wounds appears to be vascular rather than topical (LaVan and Hunt, 1990). Although wound oxygenation influences epithelialization, ultimately the rate of wound perfusion depends on angiogenesis.

Oxygen and Wound Angiogenesis

Oxygen plays an important role in the revascularization of new wounds. Both the severe hypoxia which normally appears in the middle of a wound and the relative hyperoxia on the edge of the wound appear to accelerate angiogenesis. Knighton, Silver and Hunt (1981) used rabbit ear chambers with controlled oxygen tensions and

measurements of capillary density to demonstrate that the hypoxic tissue gradient in the center of the wound is essential for wound-healing angiogenesis. Although hypoxia stimulates vessel growth these researchers verified that high concentrations of oxygen on the edge of the wound were necessary to sustain capillary growth. Enhancing oxygen concentration on the wound periphery was found to accelerate the accumulation of collagen, endothelial cell migration, and new vessel growth. In the study mentioned above, Knighton et al. (1981) found capillary density varied in direct correlation with the inspired oxygen concentration. Results of other studies have shown that oxygen tension regulates the secretion of angiogenic factors by macrophages (Knighton et al., 1983).

Oxygen and the Microbicidal Function of Leukocytes

In addition to influencing rates of collagen synthesis, epithelialization, and angiogenesis, oxygen has a major role in the microbicidal function of leukocytes. Phagocytosis, the major microbicidal activity found in the wound, involves internalization of bacteria, generation of toxic oxygen products (high-energy radicals), and the destruction of the bacterial membranes as these radicals are released onto the surface of target cells (Kiebanoff, 1980). Neutrophils and other inflammatory cells (macrophages, monocytes, and eosinophills) capture oxygen molecules and convert them first into superoxide, and then into a variety of high-energy radicals such as hydroxyl, peroxide, aldehyde, hypochlorite, and hypoiodite (Hohn, 1980). These toxic substances are packaged into granules, stored in

the cellular cytoplasm, and released to perform their lethal effect on bacteria. Normal cells are able to protect themselves from these oxygen radicals by producing special enzyme systems designed to scavenge and detoxify the oxygen radicals (White & Heckler, 1990).

A 10 to 30 fold increase in leukocyte oxygen consumption (known as the "respiratory burst") has been noted during active phagocytosis. Some of this oxygen is used for energy production, but a large percentage is converted into the toxic high-energy free radicals previously mentioned (Hunt, 1988). Because these radicals cannot be produced unless oxygen is available as a substrate, the ability to kill via oxidative mechanisms is directly proportional to local oxygen tensions, especially when local pO_2 is low (Rabkin & Hunt, 1988). Macrophages and neutrophils can accomplish phagocytosis via oxygen-independent mechanisms, but their efficiency is significantly reduced and the entire phagocytosis process becomes inactivated at low tissue oxygen levels (pO_2 level less than 30 torr) (Pollock, 1987).

Because leukocyte activity is so dependent on oxygen, even the degree of hypoxia which occurs in human and animal tissue under common physiologic conditions is critical enough to seriously inhibit leukocyte function (Rabkin & Hunt, 1988). When established circulation is interrupted by surgery, wounded tissue becomes even more susceptible to microorganism proliferation, and infection creating an incidence of surgical infection of 1%-4.5% in aseptic operations,16%-25% in contaminated areas, and up to 25%-42% in highly contaminated areas (Kuhne, Ullmann &

Kuhne, 1985). Just as compromised circulation in wound tissue results in poor leukocyte function and infection, increasing circulation and oxygenation of injured tissue in any way is likely to enhance resistance to infection (Hunt ,1988).

In one of the first studies to correlate tissue oxygenation to rate of surgical infection, Hunt and Pai (1972) produced standardized subcutaneous wounds in three groups of rabbits. One group was kept under 12% oxygen, a second group under 21% and a third group under 42% (all at normal atmospheric pressure). In the hypoxic group wounds healed significantly more slowly and displayed an increased rate of infection as compared to the control group, while wound repair in the third group was accelerated by exposure to hyperoxia. Hopf et al. (1992) measured wound oxygen tension levels in 130 postoperative patients and found those patients who subsequently developed wound infections had significantly lower wound oxygen tensions than those who did not develop infections.

Research has provided evidence that clinically facilitated hyperoxia can increase the degree of bacterial killing to the same order as that achieved by antibiotics (Rabkin & Hunt, 1988). Hohn, MacKay, Halliday and Hunt (1976) studied the relationship between pO_2 and leukocyte bacterial killing. Using experimental rabbit wounds, researchers measured the rate at which granulocytes were able to kill staphylococcus aureus at oxygen tensions ranging from 0 to 150 mmHg. A direct proportion between bacterial killing rate and oxygen tension was observed along with a major loss of killing

capacity when wound tissue pO_2 fell below 30 mmHg. Knighton, Halliday and Hunt (1986) subcutaneously injected 6 groups of guinea pigs with E coli to correlate the effect of various environmental oxygen concentrations on bacterial killing. As compared to lesions which occurred in room air, researchers found 50% larger lesions and more necrosis in hypoxic environments and 50% smaller lesions and less necrosis in hyperoxic environments. These researchers established that the antibacterial effects of hyperoxia and antibiotics are independent, but additive. In a similar study, Jonsson, Hunt and Mathes (1988), injected experimental surgical skin flaps of dogs with Staphylococcus aureus. The dogs were randomized into oxygen environments of 12%, 21% , and 45%. As in the Knighton study, researchers found test infections exhibited significantly smaller lesions (p=0.05) in the hyperoxic environment as compared to infections in the hypoxic environment.

Knighton, Halliday and Hunt (1984) observed that phagocytes require oxygen to be effective in killing common surgical infection organisms as Staphylococcus aureus, E coli, Serratia marcescens, Klebsiella pneumoniae, Proteus vulgaris, and Salmonnella typhimurium. In a review of infection-oxygen studies, Rabkin and Hunt (1988) conclude that while not all organism species are highly sensitive to local pO_2 conditions, many including those involved in abscesses and wound infections exhibit a killing rate that is directly proportional to local oxygen tension.

Mechanisms of Tissue Oxygenation

Physiology of Oxygen Transport

As discussed in the previous section, peripheral tissue oxygenation is a critical component of wound repair. Oxygen is made available from the environment to each cell via the lungs, and the circulatory system. Several factors including, partial pressure of oxygen in the inspired gas (F_IO_2), partial pressure of oxygen in the arterial blood (P_aO_2), capillary flow rate, and cellular diffusion determine the amount of oxygen available to perfuse tissue (Luce, Tyler & Pierson, 1984). Of these several factors, research has suggested that F_IO_2 is the often the most important determinant of wound oxygenation (Rosenberg, et al., 1990; Chang, et al., 1983; Silver 1978). Neural control of vascular smooth muscle has also been identified as an important regulator of tissue oxygenation (Chang et al., 1983). Other research has shown that the amount of oxygen transferred by diffusion is determined by the P_aO_2 driving force not by the volume of oxygen in the red cell. While hemoglobin is necessary to carry oxygen, its oxygen-carrying capacity is not an important determinate of wound healing since the wound extraction ratio is small (Hunt & Pai, 1972).

These findings would lead clinicians to use therapies that maximize F_IO_2, capillary flow rate and $P_{sc}O_2$ when compromised peripheral wound perfusion is suspected. Unfortunately, additional factors such as pain, cold, fever, vasoconstriction (sympathetic discharge) or vagal response, hydration status, edema, constricting

sutures, remaining dead tissue, and posture also are likely to cause a decrease in local wound oxygenation. To determine whether or not adequate tissue oxygenation is present, accurate measurement of oxygen tension in wounds is necessary. These measurements provide clinicians with the information to guide therapy that may reduce wound complications and morbidity rates (Jonsson et al., 1991).

Indirect Measures of Tissue Perfusion

Indirect measures of tissue perfusion, include cardiac output, venous pressure, pulmonary artery wedge pressure, blood pressure, and urine output. Although clinicians follow currently accepted standards for each of these variables, such standards often provide adequate systemic hydration, but fail to serve as optimal markers of wound/tissue oxygenation. Jonsson et al. (1991) found that indirect measures of tissue perfusion as observed by experienced clinicians correlated poorly with actual tissue oxygenation measurements. As will be discussed later, the use of indirect measures of tissue perfusion often place patients in considerable, unnecessary risk for wound complications and infection.

Direct Measures of Tissue Perfusion

Because oxygen measured at the tissue level is the most representative of the efficacy of tissue perfusion, a number of systems have been developed in an attempt to provide a meaningful direct measurement. Initially, Xenon clearance and technetium

scanning were used to measure tissue oxygen perfusion, but are very cumbersome for clinical use (Hunt, 1991). Transcutaneous oxygen tension ($P_{tc}O_2$) measurements were initially used to predict the healing potential of amputation stumps. Measurements were made at the level of the proposed amputation while patients lay in a reclining position (Harward et al., 1985). Transcutaneous measurements actually measure arterial, not tissue pO_2 (Sheffield, 1988). Transcutaneous oxygen measurements are now generally not accepted as accurate since the measurement technique requires that skin be heated until vasodilation occurs to obtain oxygen concentrations. This causes a major change in local perfusion and alters the oxygen-hemoglobin dissociation curve of the blood in the skin (Tremper, Waxman, & Shoemaker, 1981).

Oxygen tension measurements in subcutaneous tissue are sensitive indicators of local and total body perfusion since capillaries in subcutaneous tissues are the first to constrict in the presence of volume deficit and the last to dilate in response to therapy (Chang et al., 1983). Additionally, subcutaneous tissue is easily accessible, consumes a constant small amount of oxygen, and is often involved in surgical infections (Gottrup et al., 1987). Subcutaneous oxygen tension ($P_{sc}O_2$) has proven to be a valuable, accurate direct measurement of local tissue perfusion. It does not require manipulation of local perfusion and is more sensitive to changes in the patient's hemodynamic status and peripheral perfusion than urine output, cardiac output, $P_{tc}O_2$, or blood pressure, (Gosain et al., 1991; Gottrup et al., 1983; Gottrup et al., 1987). To

measure $P_{sc}O_2$ a sterile Silastic catheter is placed into subcutaneous tissue and a polarographic oxygen electrode or fluorescent optical probe is introduced to obtain the measurement.

Determining Subcutaneous Blood Flow (BF$_{sc}$)

The Fick principle states that blood flow or perfusion is equal to oxygen consumption divided by the amount of oxygen extracted from the blood, or the arteriovenous oxygen content difference:

blood flow or perfusion = O_2 consumption/oxygen extracted

Under stable conditions, oxygen consumption in subcutaneous tissue is assumed to be constant (Gottrup et al., 1987; Jonsson et al., 1987). Therefore oxygen extracted and flow are reciprocally related by a constant:

perfusion X oxygen extracted = constant

As blood flow or perfusion falls, the amount of oxygen extracted per unit volume must increase. Conversely, as blood flow or perfusion increases, the amount of oxygen extracted per unit volume is reduced (Jonsson et al., 1987). Because healing tissue constantly extracts only about 0.7 mL oxygen per 100 mL of perfusing blood, its mean extracellular fluid pO_2 is similar to its venous pO_2. Thus, tissue pO_2 ($P_{sc}O_2$) near a capillary is indistinguishable from the pO_2 in the capillary itself (Gottrup et al., 1987; Evans & Naylor, 1966,).

Taking these concepts together, when perfusion is adequate $P_{sc}O_2$ rises as P_aO_2 increases even to levels above full hemoglobin

saturation. When perfusion is poor (due to vasoconstriction or other disturbance in flow) the amount of oxygen extracted and used per unit volume (extraction ratio of oxygen) rises. This results in a reduction in the venous pO_2 and $P_{sc}O_2$ (Gottrup et al., 1987). Clinically, a lack of response in the $P_{sc}O_2$ to breathing increased oxygen, suggests increased oxygen extraction in subcutaneous tissue and identifies poor subcutaneous perfusion (Jonsson et al., 1987).

Jonsson et al. (1991) defined a "perfusion score" based on the Fick principle. These researchers assigned an ordinal scale "perfusion score" based on the change in the patient's $P_{sc}O_2$ as F_IO_2 was increased. The meaning of this score rests on the fact that tissue oxygen tension can be significantly elevated by increasing F_IO_2 only if the extraction ratio of the tissue is small and hence perfusion is excellent (Jonsson, et al., 1991). Lack of response of mean $P_{sc}O_2$ to breathing oxygen suggests increased oxygen extraction in subcutaneous tissue and hence poor perfusion there (Jonsson et al., 1987). Clinically, the "perfusion score" is valuable in that it provides an indication of the adequacy of local subcutaneous blood flow or wound perfusion.

Characteristics of Poorly Perfused Wound Tissue

Several factors including, reduced cardiac output, hypovolemia, and vasoconstriction can decrease peripheral wound tissue perfusion and impede healing. Both underhydration and overhydration can reduce cardiac output to a level that interferes with circulation to the wound bed (Jones & Millman, 1990). Underhydration is a major

cause of elevated plasma catecholamine levels which contribute to wound tissue hypoxia by increasing peripheral vasomotor tone (Chang et al., 1983). Other researchers have shown that overhydration may lead to tissue edema which may also interfere with circulation to the wound bed (Heughan, 1972).

Subcutaneous vessels are especially susceptible to vasoconstrictive influences. They constrict quickly in response to small decreases in blood volume or to catecholamines. Because of this vasoconstriction, efforts to correct low arterial oxygen tension by increasing oxygen in the breathing mixture may suffice to enhance tissue oxygenation in normal individuals, but this is often not the case in surgical patients (LaVan & Hunt, 1990). Chang et al. (1983), verified that postoperative subcutaneous tissue oxygen tensions ranging from 25 to 40 mm Hg which were unresponsive to breathing oxygen commonly occur and suggested this unresponsiveness was most likely related to hypovolemia, pain, cold or other autonomic stimuli.

To determine the frequency with which surgeons encounter patients with depressed peripheral tissue perfusion and simultaneously adequate urine output, Jonsson et al. (1987) measured subcutaneous tissue oxygen in 44 postoperative patients. Twelve of the thirty patients who underwent major abdominal and flank operations were found to have suboptimal tissue oxygen tension despite adequate fluid maintenance as determined by urine output. These researchers concluded that a significant number of abdominal surgery patients are not optimally perfused. The widely

held belief that urine output reflects tissue perfusion ignores the fact that subcutaneous vessels vasoconstrict and reduce perfusion long before urine output declines. Chang et al. (1983) measured the partial pressure of oxygen in mastectomy wounds and needle induced wounds in subcutaneous tissue of the arms of 33 other post-operative patients to assess postoperative tissue-wound oxygenation and perfusion. Compared with nonoperated controls, hypoxic wounds were common and most pronounced after abdominal, vascular, and cardiac procedures. Wound hypoxia was most severe immediately after the operation and lessened over several days. Based on hydration assessments of cardiac output, hematocrit, and body temperature, the presence of wound hypoxia was generally not detected even by experienced surgeons.

Improving Tissue Perfusion

Because there is a strong case for optimizing wound-tissue oxygenation in postoperative patients, suggested therapies including application of heat, increasing F_IO_2, administration of vasodilators, and prescribed exercise have been used to improve local tissue perfusion.

Perhaps the simplest means of increasing local perfusion is the application of heat. In a study of the effect of local hyperthermia on subcutaneous tissue oxygen tension and perfusion, Rabkin and Hunt (1987), found a linear correlation between subcutaneous temperature and the change in subcutaneous oxygen tension Application of heat increased subcutaneous tissue temperature 4.0°

C. resulting in an increased subcutaneous oxygen tension of 39.5 torr, an 80% increase from baseline. Other studies have shown local hyperthermia produced by intermittent infrared irradiation increases wound tensile strength in rats (Niinikoski, Rajamak & Kulonen, 1971).

Due to the effects of vasoconstriction, increasing F_IO_2 to improve tissue perfusion may have limited success, although some researchers have demonstrated that increasing inspired F_IO_2 resulted in a significant increase in tissue oxygen levels provided perfusion was adequate (Chang et al., 1983; Silver, 1978). Goodson et al. (1979) observed significant (p=0.05) increases (10%-26%) in mastectomy wound oxygen tensions when patients breathed 40% oxygen by mask.

Hunt and Hussain (1992) have noted that low $P_{tc}O_2$ in patients taking beta adrenergic blocking agents, improved with substitution of alpha adrenergic blockade. Vasodilator substances have been used clinically in patients with impaired blood supply from vascular disease, but have not been used in the critical care setting for wound healing purposes (Orgill & Demling, 1988).

Physiological Response to Exercise

As exercise begins, circulation to skin and inactive muscle is reduced by the increase in sympathetic vasoconstrictor activity. Thereafter, as body temperature rises, skin blood flow increases. The increased temperature is sensed by thermosensitive neurons in the hypothalmus and the spinal cord activating a vasodilatory

system that supplies cutaneous arterioles. The resulting increase in skin blood flow is proportional to the body temperature (Berne & Levy, 1990). Using a technique of Xenon clearance, Nielsen, Staaberg, Nielsen and Sejrsen (1988) studied subcutaneous blood flow (BF_{SC}) simultaneously in upper arm and lower limbs during positional changes and leg exercise in seven healthy males. Twenty heel-raisings per minute in a nearly erect posture increased BF_{SC} by 96% at the thigh, 25% at the calf, and 18% at the ankle. At a rate of 40 heel-raisings/minute the BF_{SC} increased 99%, 121% and 44% respectively. A general vasodilatory response did not occur because the BF_{SC} actually decreased in the arm during these exercises. Researchers attributed the observed increases in BF_{SC} to a reduction in venous pressure from the increased action of the musculo-venous pump in the lower extremities.

Because of the associated increase in blood flow to peripheral tissue, the physiological responses mentioned above may have significant application to the field of wound healing. The time-honored but unproven principle that injured tissues must be put to rest is being seriously questioned and found lacking (Salter, 1989). Newburger's (1943) work with rats was among the first studies of the influence of exercise on wound healing. Tensile strengths of standardized laparotomy wounds were measure at three, five, and ten days in animals which were kept at rest and in others which were exercised. Wounds of the exercised animals healed more rapidly and were stronger than the wounds of the animals kept at rest.

Much of the research involving postoperative activity and wound healing has centered around the use of continuous passive motion (CPM). Wong, Lotke, and Ecker (1986) found CPM reduced wound complication rates from 15 to 4 percent in a randomly studied group of 120 total knee arthroplasty patients. To compare the results of CPM and cast immobilization on surgical wound healing, Van Royen, O'Driscoll, Dhert, and Salter (1986), performed bilateral skin incisions and knee arthrotomies on ten mature rabbits. One knee was immobilized in a cast while the other was treated by CPM for three weeks. The CPM treated wounds were significantly stronger and tougher and exhibited superior collagen fiber structural orientation than those in the casted group.

Although the hypothesis that continued passive motion (CPM) accelerates surgical wound healing has been validated by several scientific investigations (Salter, 1989), few have addressed the physiological mechanisms by which CPM influences wound healing. General hypotheses such as: CPM enhances the nutrition and metabolic activity of the wound (Salter, 1989); CPM reduces swelling (Romness & Rand, 1988); and CPM aids in collagen orientation of healing wounds (Van Royen, et al., 1986) reflect the limited understanding of physiological activities affected by this postoperative activity.

Among the many questions that remain concerning the relationship between wound healing and physical activity are: 1) the degree to which various levels and types of activity affect BF_{sc} and wound healing; 2) the duration of the change of BF_{sc} after exercise;

3) the most favorable timing of post-operative activity (early postoperative days or later in the healing process).

Purpose

The purpose of this study was to compare the early postoperative effects of an enhanced postoperative activity protocol with conventional care on subcutaneous blood flow and subcutaneous tissue oxygen tension in orthopedic surgical patients having total hip replacement at a large medical school hospital in the Northwest United States. The study tested the following hypotheses: 1) Increased postoperative activity will increase subcutaneous oxygen tension; and 2) Increased postoperative activity will increase subcutaneous blood flow.

Chapter III

Methodology

Design

This study used a randomized two group experimental repeated measures design to determine if $P_{sc}O_2$ and subcutaneous blood flow are greater in orthopedic surgery patients receiving enhanced postoperative activity compared to standard postoperative activity. Patients were randomized into control and experimental groups and baseline $P_{sc}O_2$ and subcutaneous blood flow were determined in both groups prior to experimental group intervention. Post-intervention measurements were obtained on postoperative days one and two.

Sample

A convenience sample of ten orthopedic surgical patients with degenerative joint disease, scheduled for total hip replacement, was chosen. Patients were recruited from the orthopedic surgery service at large medical school hospital in the Northwest United States because they represented a relatively homogeneous group of healthy individuals with significant surgical wounds. Patients with hip replacement follow an explicitly prescribed physical activity routine which can be closely monitored and easily modified to increase activity.

Patients between 45-75 years with the ability to speak and read English were considered for inclusion into the study. Exclusion

criteria included significant cardiac disease (myocardial infarction within the last 12 months, arrhythmias, angina, or congestive heart failure), pulmonary disease, and renal disease. Patients with limited mobility due to severe arthritis, infection in an existing hip prosthesis, diabetes, rheumatoid arthritis, or those with a recent use of diuretics, beta blocking drugs, or steroids were also excluded.

Because of the narrow study population and the exacting inclusion and exclusion criteria, a limited the number of patients were available as potential study participants. Woods (1988) suggested that a convenience sampling is appropriate when design complexity and limited population present a situation in which no reasonable alternative exists. Through the use of a random number table, study participants were divided into control and experimental groups. Randomization reduces the variability due to extraneous variables by distributing them randomly between two groups (Mitchell, 1988).

Measurements

The independent variable was the prescribed postoperative activity or exercise level. The dependent variables were subcutaneous oxygen tension ($P_{sc}O_2$) and subcutaneous blood flow (BF_{sc}) near the surgical wound. Various descriptive data were collected to characterize the sample, verify similarity of the groups, and document potential confounding variables.

Prescribed Postoperative Activity

The control group received the conventional postoperative activity and exercise for patients undergoing hip replacement surgery. Conventional activity included: turning every two hours on the day of surgery and the first postoperative day; bilateral, calf-length, intermittent pressure stockings; one treatment with physical therapy on the first postoperative day and two treatments on the second postoperative day. The experimental group followed an enhanced activity program in addition to the standard postoperative activity. On the day of surgery the enhanced activity plan added prescribed sets of exercises at 2 hour intervals which included isometric quadricep, gluteal, ankle pump, and active upper arm range of motion exercises. On the first postoperative day more exercises were added which included upper arm strengthening exercises with an elastic band (Theraband) and additional walking. Standard and enhanced protocols are presented in Appendix A.

Subcutaneous Oxygen Tension

Subcutaneous oxygen tension ($P_{sc}O_2$) was defined as the partial pressure of oxygen in the subcutaneous tissue near the surgical wound. The silastic tonometer method of measuring $P_{sc}O_2$ has been used in humans and animals (Jonsson, 1991). A similarly designed Tissue Oxygen Probe System (TOPS®) manufactured by Baxter InterSpace® of Irvine, CA. was used in this study. This system uses a silastic tonometer and a fiberoptic/fluorescent oxygen sensor to

measure partial pressure of oxygen (pO_2) in millimeters of mercury (mmHg) and a thermocouple to measure temperature in degrees Centigrade (C^o).

The TOPS®system uses a phenomenon know as "fluorescence quenching" to measure PO_2 through an optode coated with a specific light emitting, fluorescent dye. Quenching is the ability of oxygen to absorb energy from excited states of fluorescent dye, preventing the energy from being radiated as light (Opitz & Lubbers, 1987). Fluorescent emission is diminished in direct proportion to the amount of oxygen present.

Instrument calibration was accomplished through an internal calibration system. A calibration code, specific to the optical characteristics of each probe was entered along with an altitude setting to adjust for the effects of barometric pressure. During a cable test, the system verifies the optical integrity of the cable (Baxter Interspace, 1991). Optode measurements of P_aO_2 and standard blood gas analysis of P_aO_2 have been shown to correlate at .96 or greater (Barker et al., 1987). Reliability tests indicate optodes produce stable pO_2 measurements over 48 hours. Accuracy of pO_2 measurements have been established as: $\pm$ 3 mmHg for pO_2 between 0-100 mmHg and $\pm$ 5% for pO_2 between 100-3600 mmHg. Temperature accuracy is $\pm$ 0.5 C^o for temperatures between 5°-45° C (Baxter Interspace, 1991).

$P_{sc}O_2$ measurements were accomplished by placing the optode inside a saline filled, gas-sterilized Silastic catheter (Baxter InterSpace®) which had been placed in the subcutaneous tissue of

the lateral thigh (near the surgical wound). Because the Silastic tubing is permeable to oxygen, the optode actually measured the mean pO_2 of the saline inside the Silastic tube which reflects pO_2 of the extracellular fluid in contact with the external surface of the Silastic tube. Niinikoski and Hunt (1972) found Silastic tubes highly permeable to oxygen, but impermeable to fluids and bacteria. In their studies, the saline within the tube was shown to equilibrate to the average pO_2 level of the tissue surrounding the tube.

Gottrup et al. (1991) found the mean tissue pO_2 was modified somewhat from normal by the trauma of tube insertion, but the chemical inertness of the Silastic tubing minimized the inflammatory reaction around the tube. $P_{sc}O_2$ was observed to fall slightly for a few days after the Silastic tube was implanted, probably due to increased cellularity resulting from inflammation and fibroplasia. To minimize this effect, measurements were discontinued 48 hours after the Silastic tubing was placed.

Subcutaneous blood flow

Subcutaneous blood flow (BF_{sc}) or perfusion was calculated using the Fick principle which states that blood flow is equal to oxygen consumption divided by the amount of oxygen extracted from the blood, or the arteriovenous oxygen content difference:

$$\text{perfusion} = O_2 \text{ consumption/oxygen extracted}$$

A "perfusion score" was calculated based on the Fick principle. The usefulness of this score rests on the fact that tissue oxygen tension can be significantly elevated by increasing F_IO_2 only if the extraction ratio of the tissue is small and hence perfusion is excellent (Jonsson et al., 1991). Conversely, if subcutaneous tissue perfusion is poor, the extraction ratio of oxygen rises, and in response to an enhanced F_IO_2 the measured $P_{sc}O_2$ becomes increasingly less responsive to changes in P_aO_2 (Gottrup et al., 1987). "Perfusion scores" were determined according to the change in the patient's $P_{sc}O_2$ as F_IO_2 was increased from .21 to .50. If $P_{sc}O_2$ rose 20% or more a score of 1 was assigned. If $P_{sc}O_2$ response was less than 20% a score of 0 was recorded. Clinically, the "perfusion score" is valuable in that it provides an indication of the adequacy of local subcutaneous blood flow or wound perfusion (Jonsson et al., 1991).

Descriptive Data

Additional descriptive data was collected on each patient. Data recorded included: type of surgical procedure, length of the procedure, estimated blood loss, medical diagnoses, age, intake and output, medication use prior to and during hospitalization, height and weight, vital signs, subjective pain ratings, arterial oxygen saturations, use of supplemental oxygenation, and wound observations.

Procedure

At the end of each hip replacement procedure a 15 cm length of medical-grade Silastic catheter tubing (1 mm outer diameter, 0.8 mm inner diameter) swaged to a modified 18-gauge spinal needle on one end and to a 22 gauge Luer lock intravenous catheter on the other was placed in the upper thigh approximately 6-8 cm from the surgical incision. With the patient still under general anesthesia, the orthopedic surgeon passed the spinal needle through the skin 3 to 5 mm deep, proceeded along the subcutaneous tissue plane, and then brought the needle out through the skin approximately 7 cm from the insertion site. The attached Silastic tube was then pulled through the subcutaneous tissue and the needle was removed, leaving the hub at the entry site and the free catheter end at the exit site. The catheter was secured in place using a sterile transparent, adhesive dressing to cover both the skin entry and exit sites. A bulky dressing was placed to protect the entire area.

$P_{sc}O_2$ measurements were first obtained 1 to 3 hours following the operation and then each morning through the second post-operative day. While the patient breathed room air, the fluorescent oxygen optode was inserted through the hubbed end of the Silastic catheter. The air in the catheter was displaced with saline. (To speed the equilibration procedure, nitrogen was bubbled through the saline solution to remove dissolved oxygen.) Thirty minutes was allowed to reach thermal and gaseous equilibrium. A $P_{sc}O_2$ baseline was defined when the readings varied less than 1-2 mm Hg for 5 minutes. Supplemental oxygen was then administered by mask at 6

Liters/minute (F_IO_2 of 0.5) and $P_{sc}O_2$ was recorded at 5-minute intervals. Maximum $P_{sc}O_2$ was recorded after at least 30 minutes on oxygen. Measurement data was periodically recorded manually and after session completion, data from the continuous monitoring was transmitted into a spreadsheet software program of a receiving computer. $P_{sc}O_2$ measurements on room air and with supplemental oxygen were completed a total of 30 times, three sessions on 10 different patients.

Subjects in the control and experimental groups were instructed through demonstration and practice sessions regarding the appropriate postoperative activity and exercises as described in the previous section. To monitor compliance with activity protocol, patients were seen twice by the primary investigators on the first and second postoperative days. Nursing and physical therapy staff were enlisted to assist with supervising and recording the prescribed activity/exercise protocols.

All measurements and data collection were conducted by the principal investigators. Additional daily observations were recorded regarding still and movement pain ratings (using a 1-10 pain scale), vital signs, supplemental oxygen use, IV solution and rate, intake and output, laboratory values, medications, and wounds for signs of infection. After the measurements on the second postoperative day, the Silastic catheter was removed by study investigators.

Protection of Human Subjects

Prior to data collection, this study was approved by the Medical Center and the University of Washington Human Subjects Review Committees. Permission for the study was also obtained from the Department of Orthopedic Surgery and the orthopedic nursing unit.

Each potential study participant was personally contacted by the primary investigators on the day of their preoperative appointment at the Medical Center Bone and Joint Clinic. Study procedures, risks and benefits were explained to each patient and informed consent and written permission were obtained. Study subjects were told that participation in the study was voluntary and that they could refuse to participate or withdraw at any time without penalty. Patients were assured of complete anonymity. Study subjects were not reimbursed for participation in the study.

Participation in the study proposed some potential risk to participants. It was not known if the enhanced activity would cause less effective wound healing, additional discomfort, tiredness, or other risks. Insertion of the Silastic catheter provided a potential site for infection. The catheter could have become caught or disconnected within the subcutaneous tissue which would necessitate surgical removal. Some discomfort may have been experienced when the catheter was removed on the second postoperative day.

Methods of Analysis

Descriptive statistics were used to describe the sample being studied. Measures of central tendency (means and standard deviations) were computed for descriptive variables with continuous data. Frequency distributions were constructed for categorical variables.

To determine if $P_{sc}O_2$ measurements changed over time, a repeated measures analysis of variance (ANOVA) was used. Perfusion scores between groups were compared using the Mann Whitney U test. Depending on the level of measurement, the Mann Whitney U test, repeated measures ANOVA, Fisher's Exact Test, or Student's t -test were applied to various descriptive variables to compare differences between the control and experimental groups. Differences were considered statistically significant when $p < 0.05$.

Chapter IV

Results

The purpose of this experimental study was to compare the early postoperative effects of an enhanced postoperative activity protocol (experimental group) with conventional postoperative activity (control group) on $P_{sc}O_2$ and BF_{sc}. $P_{sc}O_2$ was measured to establish a baseline on three consecutive postoperative days. On each day BF_{sc} was determined based on the increase of the patient's $P_{sc}O_2$ in response to breathing oxygen ($F_iO_2 = 50\%$) for 30 minutes.

Description of Sample

Four men and 6 women between the ages of 47 and 74 who met the inclusion criteria were entered into the study. One study participant had a preoperative diagnosis of acetabular fracture; all other patients had a preoperative diagnosis of degenerative joint disease. Each patient underwent an elective total hip replacement at the hospital study site. All patients received standard postoperative medications including vitamins, antibotics, and laxatives and used bilateral automatic compression stockings. All patients did well postoperatively without development of surgical complications or infection. All patients were discharged on postoperative day 5 or 6.

Demographic Data

Demographic data collected included gender, age, height, weight, history of recent weight change, preoperative hemoglobin and hematocrit, preoperative medication use, type of anesthesia, length of surgery, estimated blood loss, and intake and output during surgery (Table 1). Student's t-test was used to compare the control and experimental group characteristics based on age, weight, preoperative hemoglobin and hematocrit, length of surgery, estimated blood loss, and intake and output during surgery. Group characteristics were found to be similar except for preoperative hemoglobin, (t=-3.09; p=0.021).

Independent Variables

Postoperative Activity Protocol.

Measures of postoperative activity (number of isometric exercise sets, ambulation frequency and distance, number of times patient moved to sit in a chair) were recorded by direct observation and from nursing notes and physical therapy records. Patients in both groups followed the same turning schedule and physical therapy treatment plan. Group means and standard deviations were calculated and support that the enhanced postoperative activity group was involved in a higher level of activity (Table 2).

TABLE 1. Group Demographic Data For All Subjects

	*Conventional Postoperative Activity	*Enhanced Postoperative Activity
Number of Subjects	5	5
Gender (Male/Female)	0/5	4/1
Age (years)	65 ± 10.7	66.4 ± 6.2
Height (inches)	62.7 ± 1.86	69.4 ± 3.7
Weight (Kg)	61.4 ± 10.3	88.0 ± 21.3
Recent Weight Chg (Y/N)	0/5	0/5
Smoking History (Y/N)	4/1	2/3
Quit Smoking (yrs since)	9.9 ± 10.7	17.5 ± 14.8
Hemoglobin (gm/dl)	11.45 ± 0.98	13.7 ± 1.27
Hematocrit (%)	36.4 ± 5.41	40.7 ± 4.16
NSAID use (Y/N)	4/1	3/2
Diuretic use (Y/N)	0/5	1/4
Cardiac Med use (Y/N)	1/4	1/4
Pain Med use (Y/N)	1/4	1/4
Anaesthetic (Gen/Gen+Epi/Epi)	0/5/0	3/1/1
Length of Surgery (hours)	4.25 ± 0.62	4.13 ± 0.83
Estimated Blood Loss (L)	0.45 ± 0.13	0.78 ± 0.36
OR - IV Fluid intake (L)	3.28 ± 0.69	3.98 ± 1.11
OR - Blood intake (units)	0.4 ± 0.54	0.0 ± 0.0
OR - Urine output (L)	0.73 ± 0.41	0.37 ± 0.10
PACU - IV Fluid intake (L)	0.61 ± 0.25	0.30 ± 0.29
PACU - Urine output (L)	0.26 ± 0.18	0.16 ± 0.08

* Frequency or Mean ± Standard Deviation

TABLE 2. Postoperative Activity

	*Conventional Postoperative Activity (n=5)	*Enhanced Postoperative Activity (n=5)
Postoperative Day 0		
Isometric Exercise/Unit (sets)	0 ± 0	2.8 ± 1.3
Theraband Exercise/Unit (sets)	0 ± 0	0 ± 0
Ambulation/Unit (occurrences)	0 ± 0	0 ± 0
Ambulation Distance/Unit (ft)	0 ± 0	0 ± 0
Isometric Exercise/PT (sets)	0 ± 0	0 ± 0
Ambulation/PT (occurrences)	0 ± 0	0 ± 0
Ambulation Distance/PT (ft)	0 ± 0	0 ± 0
Up to Sit in Chair (occurrences)	0 ± 0	0 ± 0
Postoperative Day 1		
Isometric Exercise/Unit (sets)	2.8 ± 3.8	9.6 ± 1.1
Theraband Exercise/Unit (sets)	0 ± 0	2.8 ± 0.4
Ambulation/Unit (occurrences)	0 ± 0	0 ± 0
Ambulation Distance/Unit (ft)	0 ± 0	0 ± 0
Isometric Exercise/PT (sets)	0.8 ± 0.4	0.8 ± 0.4
Ambulation/PT (occurrences)	0.4 ± 0.5	0 ± 0
Ambulation Distance/PT (ft)	2.8 ± 4.4	0 ± 0
Up to Sit in Chair (occurrences)	0 ± 0	0.6 ± 1.3
Postoperative Day 2		
Isometric Exercise/Unit (sets)	5.4 ± 3.1	7.2 ± 2.8
Theraband Exercise/Unit (sets)	0.2 ± 0.4	6.8 ± 3.1
Ambulation/Unit (occurrences)	1.4 ± 1.3	1.4 ± 0.5
Ambulation Distance/Unit (ft)	14.0 ± 13.4	51.0 ± 12.5
Isometric Exercise/PT (sets)	0.8 ± 0.4	0.6 ± 0.9
Ambulation/PT (occurrences)	1.0 ± 0	1.2 ± 0.8
Ambulation Distance/PT (ft)	31.0 ± 17.5	99.0 ± 126.8
Up to Sit in Chair (occurrences)	1.0 ± 0	.8 ± 1.3

* Frequency or Mean ± Standard Deviation
n = 5 subjects in each group

Contributing Patient Attributes.

Reported levels of pain, use of oral, IV, or epidural narcotics, oral and IV intake, urine output, current inspired oxygen percentage, hemoglobin and hematocrit, vital signs (blood pressure, heart rate, respiratory rate, and temperature), baseline arterial hemoglobin saturation, subcutaneous temperature, and room temperature were recorded on each observation day. Frequencies and group means were calculated (Tables 3, 4, and 5).

Repeated measures analysis of variance (ANOVA) was used to test for differences related to the group assignment for the following variables: reported levels of pain (when still and when moving), hemoglobin, hematocrit, blood pressure, heart rate, temperature, oral and IV intake, urine output, baseline arterial hemoglobin saturation, subcutaneous temperature, and room temperature. Significant group differences (F=114.29; p=0.0001) were identified in reported still pain (control mean ± SD=2.47 ± 2.25; experimental mean ± SD=1.13 ± 1.31). Similar group differences (F=25.11; p=0.0001) were found in movement pain (control=4.00 ± 3.41; experimental=3.07 ± 1.53). Systolic blood pressure also differed significantly (F=13.04; p=0.0004) between the control (122.6 ± 16.9 mmHg) and experimental (118.9 ± 14.3 mmHg) groups.

Fisher's Exact Test was used to test for group assignment differences related to type of operative anesthesia (general or epidural). No statistically significant differences were identified.

TABLE 3. Contributing Patient Attributes - Postoperative Day 0

	*Conventional Postoperative Activity (n=5)	*Enhanced Postoperative Activity (n=5)
Still Pain Level (0-10 scale)	2.0 ± 2.0	1.8 ± 1.8
Moving Pain Level (0-10 scale)	2.8 ± 2.8	3.4 ± 2.6
Oral Narcotics (Y/N)	0/5	0/5
IV Narcotics (Y/N)	1/4	2/3
Epidural Narcotics (Y/N)	4/1	4/1
Local Epidural Narcotics (Y/N)	2/3	2/3
Oral + IV Intake (L)	1.23 ± 0.59	1.15 ± 0.32
Blood Intake (units)	0 ± 0	0 ± 0
Urine Output (L)	0.54 ± 0.21	0.60 ± 0.3
Inspired Oxygen (%)	22.4 ± 3.1	24.6 ± 5.1
Hemoglobin (gm/dl)	9.9 ± 1.4	9.3 ± 0.8
Hematocrit (%)	29.6 ± 4.0	31.4 ± 4.6
Systolic BP (mmHg)	120.2 ± 18.5	117.2 ± 13.8
Diastolic BP (mmHg)	69.2 ± 19.3	66.2 ± 5.5
Heart Rate (bpm)	84.2 ± 13.2	77.8 ± 22.5
Respiratory Rate (rpm)	16.8 ± 3.0	15.6 ± 3.6
Oral Temperature (C)	36.1 ± 1.5	36.6 ± 0.8
Room Temperature (C)	24.6 ± 1.6	23.8 ± 0.8
Arterial O_2 Saturation (%)	94.0 ± 4.8	97.2 ± 0.8
Subcutaneous Temp (C)†	35.8 ± 1.4	35.7 ± 1.3

* Frequency or Mean ± Standard Deviation
† n=4 (conventional group), n=5 (enhanced group)

TABLE 4. Contributing Patient Attributes - Postoperative Day 1

	*Conventional Postoperative Activity (n=5)	*Enhanced Postoperative Activity (n=5)
Still Pain Level (0-10 scale)	3.6 ± 2.8	1.2 ± 1.3
Moving Pain Level (0-10 scale)	5.2 ± 4.3	3.0 ± 1.0
Oral Narcotics (Y/N)	1/4	3/2
IV Narcotics (Y/N)	2/3	2/3
Epidural Narcotics (Y/N)	4/1	4/1
Local/Epidural Narcotics (Y/N)	2/3	1/4
Oral + IV Intake (L)	2.81 ± 0.86	3.54 ± 1.79
Blood Intake (units)	0.68 ± 0.83	0.2 ± 0.44
Urine Output (L)	2.28 ± 0.91	2.81 ± 1.82
Inspired Oxygen (%)	26.2 ± 8.3	21.0 ± 0.0
Hemoglobin (gm/dl)	9.2 ± 0.8	9.6 ± 0.8
Hematocrit (%)	27.4 ± 2.7	28.2 ± 2.4
Systolic BP (mmHg)	117.6 ± 17.2	109.2 ± 13.5
Diastolic BP (mmHg)	60.2 ± 11.6	59.0 ± 5.5
Heart Rate (bpm)	92.2 ± 12.0	85.4 ± 16.1
Respiratory Rate (rpm)	17.6 ± 2.2	16.0 ± 0.0
Oral Temperature (C)	37.7 ± 0.8	38.1 ± 0.5
Room Temperature (C)	23.9 ± 1.1	23.2 ± 0.7
Arterial O_2 Saturation (%)	90.8 ± 7.6	96.2 ± 1.3
Subcutaneous Temp (C)†	37.3 ± 0.8	36.8 ± 1.08

* Frequency or Mean ± Standard Deviation
† n=4 (conventional group), n=5 (enhanced group)

TABLE 5. Contributing Patient Attributes - Postoperative Day 2

	*Conventional Postoperative Activity (n=5)	*Enhanced Postoperative Activity (n=5)
Still Pain Level (0-10 scale)	1.8 ± 2.0	0.4 ± 0.5
Moving Pain Level (0-10 scale)	4.0 ± 3.7	2.8 ± 0.8
Oral Narcotics (Y/N)	4/1	4/1
IV Narcotics (Y/N)	1/4	1/4
Epidural Narcotics (Y/N)	3/2	1/4
Epidural/Local Narcotics (Y/N)	1/4	1/4
Oral + IV Intake (L)	2.09 ± 1.10	2.18 ± 1.01
Blood Intake (units)	0 ± 0	0.4 ± 0.55
Urine Output (L)	2.47 ± 0.57	2.41 ± 0.71
Inspired Oxygen (%)	24.8 ± 8.4	21.0 ± 0
Hemoglobin (gm/dl)	10.0 ± 0.78	9.1 ± 0.9
Hematocrit (%)	29.6 ± 2.88	27.2 ± 3.3
Systolic BP (mmHg)	130 ± 17.8	130.4 ± 10.5
Diastolic BP (mmHg)	66.8 ± 22.2	70.4 ± 9.7
Heart Rate (bpm)	84.2 ± 14.3	85.4 ± 10.7
Respiratory Rate (rpm)	18.0 ± 3.5	20.0 ± 1.4
Oral Temperature (C)	37.6 ± 0.7	38.0 ± 0.4
Room Temperature (C)	24.0 ± 1.2	23.6 ± 1.0
Arterial O_2 Saturation (%)	90.0 ± 5.6	95.2 ± 2.9
Subcutaneous Temp (C)†	36.5 ± 1.2	37.1 ± 0.8

* Frequency or Mean ± Standard Deviation
† n=4 (conventional group), n=5 (enhanced group)

<u>Dependent Variables</u>

<u>Subcutaneous Oxygen Tension.</u>

To test the study hypothesis: "increased postoperative activity will have a positive effect and increase subcutaneous oxygen tension," $P_{sc}O_2$ was measured on postoperative day 0, 1, and 2. Group means were determined (Table 6). Repeated measures ANOVA was used to test for differences related to protocol and time (Table 7). $P_{sc}O_2$ was significantly different (F=21.94; p=0.0016) between activity protocol groups. On day 0, group differences were not significant, but on days 1 and 2 significant group differences were observed (p=0.0019 and p=0.0034). The F value for $P_{sc}O_2$ by time without regard for protocol was not significant. These findings did not support the study hypothesis that enhanced activity increases subcutaneous oxygen tension.

<u>Subcutaneous Blood Flow</u>

To test the hypothesis: "increased postoperative activity will increase subcutaneous blood flow," a "perfusion score" based on the Fick principle was calculated for each of the 30 patient observations. Patients were classified as well perfused and given a score of "1" if their $P_{sc}O_2$ rose 20% or more in response to breathing 50% oxygen for 30 minutes. A score of "0" was given for a lesser response to the application of supplemental oxygen (Jonsson et al., 1991). Perfusion scores between groups were compared by day using the nonparametric, Mann Whitney U test. No group differences were

TABLE 6. Baseline Subcutaneous Oxygen Tension ($P_{sc}O_2$)$^\Delta$

Group	Postop Day 0	Postop Day 1	Postop Day 2	Group Mean
Conventional Activity	57.6 ± 7.4	72.2 ± 14.2*	62.6 ± 10.9*	64.1 ± 12.1
Enhanced Activity	49.8 ± 7.3	48.4 ± 7.1	40.4 ± 14.6	46.2 ± 10.4
	53.7 ± 8.1	60.3 ± 16.4	51.5 ± 16.8	55.2 ± 14.4

$^\Delta$ Mean ± Standard Deviation
* Significantly higher than Enhanced Activity Group, RM ANOVA, $p<0.05$

TABLE 7. Repeated Measures Analysis of Variance for Baseline Subcutaneous Oxygen Tension ($P_{sc}O_2$)

Source	df†	Sum of Squares (SS)	Mean SS	F	P
Between Subjects	9	3290.17			
By Activity Group	1	2412.03	2412.03	21.974	0.0016
Error 1	8	878.13	109.77		
Within Subjects	20	2690.00			
Over Time	2	419.47	209.73	1.778	0.201
Activity Group/ Time	2	388.27	194.13	1.645	0.224
Error 2	16	1888.27	118.02		

† Degrees of Freedom

identified. Mean perfusion scores for the two protocols over time are displayed in Figure 1.

In additional analysis, using repeated measures ANOVA, the mean percentage increase in $P_{sc}O_2$ from the baseline, in response to breathing 50% oxygen was compared by group (Tables 8 and 9). $P_{sc}O_2$ was not significantly different between groups. Percent $P_{sc}O_2$ increase was found to be significant (F=2745.7; p=0.0087) for time, without regard for protocol. Post hoc comparisons using the Scheffe test, found the percent increase in $P_{sc}O_2$ on postoperative day 1 was significantly greater (p=0.0092) compared to day 2 but not to day 0. These findings did not support the study hypothesis that enhanced activity increases subcutaneous blood flow.
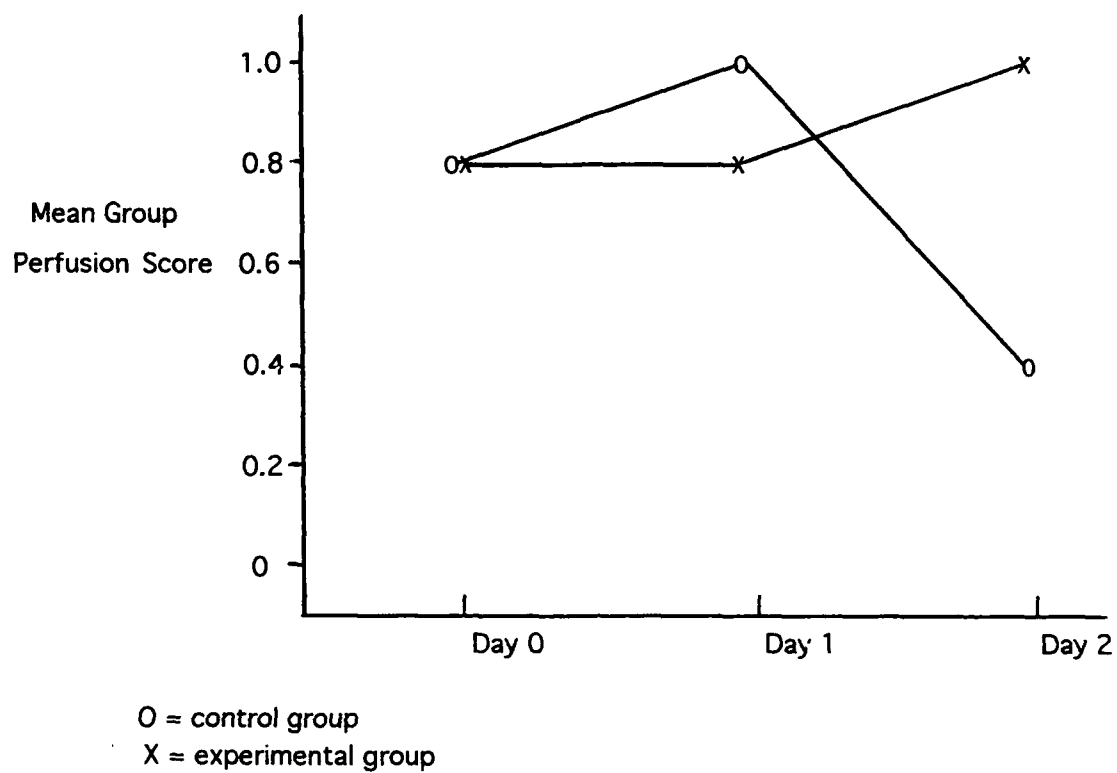
Figure 1. Subcutaneous Blood Flow (BF$_{sc}$) as Reflected by Perfusion Score

TABLE 8. Subcutaneous Blood Flow
As Reflected by Percentage of Increase in $P_{sc}O_2$ on 50% F_iO_2 $^\Delta$

Group	Postop Day 0	Postop Day 1	Postop Day 2	Group Mean
Conventional Activity	38.6 ± 24.9	73.0 ± 25.0	15.2 ± 10.5	42.3 ± 31.5
Enhanced Activity	43.2 ± 37.9	34.8 ± 16.7	26.8 ± 6.5	34.9 ± 23.4
	40.9 ± 30.3	53.9 ± 28.4*	21.0 ± 10.3	38.6 ± 27.5

$^\Delta$ Mean ± Standard Deviation of Percentage Increase
* Significantly higher than Postoperative Day 2, RM ANOVA, $p<0.05$

TABLE 9. Repeated Measures Analysis of Variance for
Subcutaneous Blood Flow
As Reflected by Percentage of Increase in $P_{sc}O_2$ on 50% F_iO_2

Source	df†	Sum of Squares (SS)	Mean SS	F	P
Between Subjects	9	6067.20			
By Activity Group	1	403.33	403.33	0.570	0.4721
Error 1	8	5663.87	707.98		
Within Subjects	20	15910.00			
Over Time	2	5491.40	2745.70	6.475	0.0087
Activity Group/ Time	2	3634.07	1817.03	4.285	0.0323
Error 2	16	6784.53	424.03		

† Degrees of Freedom

Chapter V

Discussion

Healing of peripheral tissues is particularly vulnerable to perfusion and oxygenation deficits. $P_{sc}O_2$ and BF_{sc} reflect the balance between oxygen delivery and oxygen consumption and are influenced by a variety of factors. This study has endeavored to test whether or not postoperative activity enhances $P_{sc}O_2$ and BF_{sc}. While the findings of this study did not support the proposed hypotheses, a number of important observations can be made from the data collected. The foci of this chapter is to discuss the findings of the study in the context of previous related work, the limitations of the study, practice implications, and directions for future research.

Subcutaneous Tissue Oxygen Tension

Daily baseline $P_{sc}O_2$ measurements ranged from 40±15 mmHg to 50±7 mmHg (mean ± SD) in the experimental group and 58±7 mmHg to 72±14 (mean ± SD) in the control group. These findings are similar to postoperative $P_{sc}O_2$ measurements of 59±12 mmHg to 72±18 mmHg observed by Hopf et al. (1992), 46-71 mmHg by Rosenberg et al. (1990), and 48±17 mmHg by Rabkin and Hunt (1987). In the present study one patient in the control group and no patients in the experimental group had a baseline $P_{sc}O_2 < 35$ mmHg which is thought to be the level below which wound healing and resistance to

infection is compromised (Hohn et al.,1976; Hunt, 1988; Hunt & Pai, 1972; Knighton et al., 1984; LaVan & Hunt, 1990).

Analysis of $P_{sc}O_2$ measurements revealed that the control group had higher $P_{sc}O_2$ levels than the experimental group on each of the measurement days. Statistically significant differences were found between groups on postoperative day 1 and 2. No other published reports on the effect of postoperative activity on $P_{sc}O_2$ were found so comparisons to other studies cannot be made.

Subcutaneous Blood Flow

Lack of a response (<20%) in $P_{sc}O_2$ to increased F_1O_2 suggests increased oxygen extraction in subcutaneous tissue and identifies poor subcutaneous blood flow (BF_{sc}) just as a significant (>20%) increase in $P_{sc}O_2$ to an increased F_1O_2 indicates well perfused tissue (Jonsson et al., 1987). Although an increase in $P_{sc}O_2$ in response to an increased F_1O_2 was observed during each oxygen challenge, a significant increase (>20%) was noted in only 24 of the 30 measurements. Percentage increases ranged from 27±6 to 43±38 (mean ± SD) in the experimental group and 15±10 to 73±15 (mean ± SD) in the control group. These findings generally are higher than the 24% mean $P_{sc}O_2$ increase observed in postoperative abdominal surgery patients (breathing of 10 L/m oxygen via mask) studied by Rosenberg et al. (1990). Jonsson and associates (1991) also observed patient's $P_{sc}O_2$ response to breathing oxygen (5 L/m for 20 minutes) following major abdominal operations and observed a mean increase of 57% over the first 3 postoperative days.

Comparisons of patient and group data revealed that the control group had higher percent increases in $P_{sc}O_2$ than the experimental group. Group differences on postoperative day 1 were much larger than those observed on day 0 or day 2. An analysis of BF_{sc} as reflected by "perfusion scores" on day 0 classified 4 of the 5 patients in both the control and experimental groups as well perfused. On day 1, 5/5 of the control group and 4/5 of the experimental group were well perfused. On day 2, only 2/5 of the control group were well perfused compared to 5/5 of the experimental group. Although perfusion scores from one day are not strong evidence, a positive trend of improved perfusion for the experimental group as activity progressed may have been present. No other published reports on the affect of postoperative activity on BF_{sc} were found so comparisons to other studies are not possible.

Factors Influencing Oxygen Delivery to Subcutaneous Tissue

Physical Activity

Physical activity was the independent variable in this study. It is thought to influence tissue perfusion based on type of exercise (static or dynamic), contraction strength and duration, body position, and efficacy of the muscle pump (Leyk, Ebfeld, Baum & Stegemann,1992). Patients in the enhanced activity group as compared to those in the conventional activity group participated in more isometric exercises (quadracept contractions, gluteal and ankle pump sets), theraband exercise (involving the arms), and ambulation distance. Group differences in activity were small

during day 0. Some additional differences were noted on day 1 and a clear difference between the groups was seen on day 2 (Table 2).

In tests of the study hypotheses, enhanced physical activity did not increase $P_{sc}O_2$ and BF_{sc}. However, analysis also indicated enhanced physical activity did not reduce perfusion as no differences were found between groups. A review of related research on physical activity presents three possible explanations for the rejection of the study hypothesis: short term affect of exercise on BF_{sc}, limited regional response to exercise, and study design limitations.

Short Term Affect of Exercise on BF_{sc}.

In a study of doppler ultrasound measurements of blood flow during and after exercise, Van Leeuwen, Barendsen, Lubbers, and De Pater (1992), found blood flow increased after the onset of exercise and reached a plateau depending on work load. As soon as exercise stopped, blood flow decreased rapidly (50% within 27-46 seconds in the supine position). In the present study, $P_{sc}O_2$ measurements were obtained during periods of rest, not close to any periods of exercise, so any effect related to exercise may have been undetected with the return of BF_{sc} to baseline. This could explain why increased $P_{sc}O_2$ and BF_{sc} were not identified in the measurements obtained.

Limited Regional Response to Exercise.

Using a Xenon clearance technique, Caru, Colombo, Santoro, Laporta, and Maslowsky (1992) studied the regulation of blood flow

to skeletal muscle in response to exercise. They found that muscles involved in exercise may experience a 400-500% increase in blood flow while blood flow in non-exercising organs may decrease to about 20-40% of the resting blood flow due to competing vasoconstrictor and vasodilator drives. Nielsen et al. (1988) studied BF_{sc} simultaneously in upper arm and lower limbs during positional changes and leg exercise in seven healthy males. While an increased BF_{sc} was observed in the leg, a general vasodilatory response did not occur. A decrease in arm BF_{sc} was attributed to a reduction in venous pressure from the increased action of the musculo-venous pump in the lower extremities. Theraband exercises (involving the upper arm) and ankle pumps may therefore have affected the blood flow in the involved muscle or $P_{sc}O_2$ or BF_{sc} in local tissue, but had no detectable affect on the $P_{sc}O_2$ and BF_{sc} in the upper thigh at the times of measurement in the present study.

Study Design Limitations.

An ANOVA of the baseline $P_{sc}O_2$ on day 0 (2-4 hours post by the surgery) did not detect a significant difference between the control and experimental groups, yet on day 1 at 9:00 A.M. (15-20 hours post surgery) a significant difference ($p=0.0019$) in the $P_{sc}O_2$ was evident. It would be difficult to associate this difference in group mean $P_{sc}O_2$ to the postoperative activity as the differences in group activity protocols at that time were still limited (Table 2). Later during day 1 the activity protocols began to differ to a greater extent. The group means of baseline $P_{sc}O_2$ at 9:00 A.M. on day 2

(39-44 hours post surgery) also indicated a significant difference (p=0.0034) between the two groups. This analysis would lead to the possible conclusion that the group differences on days 1 and 2 may have been associated with activity or alternatively with variables other than activity.

Additional Contributing Independent Variables

Data collected from study participants included commonly acknowledged factors which influence perfusion of oxygen to subcutaneous tissue (Tables 3, 4, and 5). Two of these independent variables, postoperative pain (still and moving) and systolic blood pressure, represented statistically significant differences between the control and experimental groups. Two other independent variables, hydration status and subcutaneous temperature, while not found to be significantly different between groups, also warrant discussion in the context of previous study.

Pain.

Pain is a major stimuli for catecholamine release (Hunt, 1988). In a study of operative stress on catecholamine levels, Nikki, Takki, Tammisto, and Jaatela (1972) found that the return of pain during the postoperative recovery period was associated with a distinct increase (about 50%) in plasma catecholamine levels. Catecholamine influences $P_{sc}O_2$ and BF_{sc} by increasing vasomotor tone (Chang et al., 1983). Repeated measures ANOVA identified differences in the

control and experimental group in levels of reported pain. The reported levels of still/movement pain for the control group were 2.5/4.0 compared to the experimental group report of 1.1/3.1. While these differences were statistically significant, these subjective self-reports of pain may not be clinically significant. Even if the differences had been significant, the higher levels of pain reported in the control group would negatively influence $P_{sc}O_2$ and BF_{sc}, which was not observed.

Blood Pressure.

Systolic blood pressure also differed significantly between the control (122.6 $\pm$ 16.9 mmHg) and experimental (118.9 $\pm$ 14.3 mmHg) groups. In a study of tissue oxygen tension and other indicators of perfusion during graded hemorrhage in dogs, Gosain et al. (1991) found mean arterial pressure did not correlate with changes in $P_{sc}O_2$. The differences observed in the present study are probably not clinically significant.

Hydration Status.

Chang and associates (1983) found underhydration to be a major cause of elevated plasma catecholamine levels and that even minor degrees of hypovolemia, undetectable by standard means such as urine output, may be responsible for significant autonomic vasconstriction in peripheral tissues. In the present study, no significant differences were observed between the control and

experimental groups in IV and oral intake or urine output. All patients received the same IV fluid at 100 cc/hour during the study period. Because subjects in the two study groups differed in weight (61 ± 10 Kg for the control group and 88 ± 21 Kg for the experimental group) some differences in hydration status may have been present. This study did not include measuring $P_{sc}O_2$ in response to a fluid challenge to assess hypovolemia in the patients who did not have a significant increase (>20%) in $P_{sc}O_2$ in response to an increased F_IO_2. Thus, differences in hydration as a possible explanation cannot be ruled out.

Subcutaneous Temperature.

Rabkin and Hunt (1987), found a linear correlation between subcutaneous temperature and the change in subcutaneous oxygen tension. In their study, the application of heat increased subcutaneous tissue temperature 4.0° C. resulting in an increased subcutaneous oxygen tension of 39.5 torr, an 80% increase from baseline. In the present study, all patients had normal core temperatures during measurements and no group differences in subcutaneous temperatures were identified.

Study Limitations

The small number of study subjects (n=10) is a limitation of this study. Gender bias between groups (control group=0 males/5 females; experimental group=4 males/1 female) probably gives rise

to the differences in group means for preoperative hemoglobin (p=0.021) and limits the generalizability of study findings.

The short period of data collection (39-44 hours post surgery) also limits this study. The short period of study was used because of concern, as reported by Niinikoski and Hunt (1972), that by postoperative day 3-5, a connective tissue capsule would form around the silastic catheter and result in errors in measured responses of $P_{sc}O_2$ to oxygen breathing.

During data collection, researchers frequently experienced difficulty in obtaining accurate, clearly descriptive activity documentation. Prior to the start of the study investigators were unable to find a previously tested method to quantify patient activity. A single score, representing the sum of a patient's daily activity, if available,would have been useful in hypothesis testing.

Implications for Nursing Practice

Because the study findings are tentative, no conclusions can be made regarding the affect of enhanced postoperative activity on $P_{sc}O_2$ and BF_{sc}. Therefore, no recommendations for nursing practice are made at this time.

Recommendations for Further Study

This study represents the initial research of a larger investigation on the effects of physical activity on wound healing. Extending data collection through postoperative day 3 or day 4

should be considered because it is during day 2 and day 3 that greater differences in activity levels may occur. Efforts to encourage and assist the nursing and physical therapy staff document the frequency and intensity of activities would provide more reliable data on levels of activity and compliance with enhanced activity protocol. Development of a method to quantify daily activity levels into an activity score, would strengthen study methods and enhance data analysis.

Similar studies could be undertaken to: 1) Compare the effects of passive motion (using on knee surgery patients) versus active motion on $P_{sc}O_2$ and BF_{sc} at one or more subcutaneous sites on the leg. Information obtained could help determine which postoperative activity is most beneficial to surgical wound healing. 2) Correlate reported postoperative pain levels with $P_{sc}O_2$ and BF_{sc} near various surgical sites prior to and after administering pain medication. This data might help to describe the effects of pain and various analgesics on tissue perfusion. 3) Continuously measure $P_{sc}O_2$ and BF_{sc} during and/or after various types of exercise to ascertain the onset and duration of $P_{sc}O_2$ and BF_{sc} changes related to exercise. 4) Compare the healing rate of open wounds for partially immobile elderly patients following different exercise protocols. Findings could assist in defining the most therapeutic type, frequency and duration of exercise and guide health care workers in prescribing beneficial activity protocols.

Research in the area of wound healing is progressing on many fronts, yet many questions concerning of the benefits of activity and

exercise remain unanswered. Nursing interventions such as prescribing, teaching, and monitoring activity and exercise are important. Additional nursing research is essential to define the effects of activity on physiologic response and to provide an empirical base for determining which activity protocols are most beneficial to enhance rapid tissue repair.

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Appendix A

<u>Postoperative Activity Protocols</u>

Conventional (Control Group)	Enhanced (Experimental Group)
<u>Day 0</u>	<u>Day 0</u>
-turning every two hours	-turning every two hours

-intermittent pressure
    stockings
	-intermittent pressure
	    stockings

	-isometric quadricep, gluteal,
	    & ankle pump exercises
	    every 2 hours while awake

	-active range of motion, upper extremeties q2 hours w/a
<u>Day 1</u>	<u>Day 1</u>
-turning every two hours	-turning every two hours

-intermittent pressure
    stockings
	-intermittent pressure
	    stockings

-physical therapy X 1	-physical therapy X 1

-isometric quadricep, gluteal,
    & ankle pump exercises
    every 2 hours while awake
	-isometric quadricep, gluteal,
	    & ankle pump exercises
	    every 2 hours while awake

	-upper arm strengthening
	    exercises with Theraband
	    q2 hours w/a

<u>Day 2</u>	<u>Day 2</u>

-intermittent pressure
    stockings
	-intermittent pressure
	    stockings

-physical therapy X 2	-physical therapy X 2

-isometric quadricep, gluteal,
    & ankle pump exercises
    every 2 hours while awake
	-isometric quadricep, gluteal,
	    & ankle pump exercises
	    every 2 hours while awake

	-upper arm strengthening
	    exe cises with Theraband
	    q2 hours w/a

	-additional walking - at least 20 feet

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